TABLE 6.—*Free-air resultant winds in "highs"*

WINTER

Altitude m. s. l.	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Surface	N. 79° W.	3.8	S. 10° W.	3.9	S. 72° E.	2.5	N. 29° W.	4.7
500	N. 72° W.	5.7	S. 21° W.	6.3	S. 68° E.	3.8	N. 26° W.	6.6
750	N. 66° W.	7.4	S. 34° W.	8.3	S. 56° E.	5.3	N. 14° W.	6.6
1,000	N. 60° W.	8.8	S. 46° W.	9.6	S. 42° E.	6.2	N. 19° W.	8.7
1,500	N. 55° W.	11.7	S. 62° W.	11.0	S. 19° E.	3.5	N. 38° W.	10.6
2,000	N. 55° W.	14.0	S. 78° W.	11.0	S. 35° W.	3.0	N. 44° W.	13.7
2,500	N. 55° W.	16.7	S. 85° W.	12.2	W.	4.1	N. 58° W.	16.4
3,000	N. 51° W.	15.6	N. 79° W.	14.6	N. 79° W.	6.1	N. 60° W.	16.6
3,500	N. 49° W.	15.1	N. 72° W.	16.0	N. 78° W.	6.7	N. 59° W.	18.6
4,000	N. 49° W.	15.2	N. 71° W.	17.3	N. 68° W.	7.5	N. 70° W.	20.6
4,500	N. 44° W.	13.5	N. 68° W.	19.2	N. 77° W.	8.9	N. 59° W.	21.4
5,000	N. 23° W.	12.7			N. 69° W.	9.6	N. 54° W.	20.4
6,000	N. 23° W.	12.5			N. 61° W.	6.0		
7,000	N. 47° W.	15.9			S. 80° W.	11.2		
8,000					S. 89° W.	8.9		

SPRING

Altitude m. s. l.	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Surface	N. 65° W.	3.2	S. 6° W.	3.8	S. 69° E.	3.2	N. 8° W.	4.3
500	N. 61° W.	4.6	S. 14° W.	6.1	S. 71° E.	4.5	N. 9° W.	5.6
750	N. 50° W.	5.3	S. 16° W.	7.0	S. 78° E.	4.7	N. 11° W.	6.2
1,000	N. 49° W.	6.2	S. 26° W.	6.7	S. 73° E.	4.5	N. 13° W.	6.7
1,500	N. 46° W.	8.4	S. 52° W.	7.6	S. 71° E.	3.3	N. 18° W.	8.6
2,000	N. 46° W.	10.2	S. 71° W.	8.4	N. 66° E.	1.5	N. 28° W.	10.6
2,500	N. 47° W.	11.6	S. 81° W.	8.3	N. 2° E.	1.1	N. 33° W.	12.0
3,000	N. 50° W.	13.2	W.	9.4	N. 47° W.	1.8	N. 37° W.	14.4
3,500	N. 49° W.	13.5	S. 86° W.	9.5	N. 30° W.	1.8	N. 56° W.	16.0
4,000	N. 46° W.	12.3	S. 83° W.	9.0	N. 68° W.	3.7	N. 56° W.	14.8
4,500	N. 49° W.	12.8	S. 73° W.	5.8	N. 67° W.	6.2	N. 53° W.	15.6
5,000	N. 52° W.	15.0	W.	7.1	N. 69° W.	5.3	N. 61° W.	18.1
6,000	N. 51° W.	14.8			N. 43° W.	5.8	N. 71° W.	18.0
7,000	N. 43° W.	10.0			N. 50° W.	4.5	N. 72° W.	21.9
8,000	N. 68° W.	12.3			N. 39° W.	11.2		
9,000					N. 52° W.	16.9		

SUMMER

Altitude m. s. l.	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Surface	N. 25° W.	2.6	S. 2° E.	3.0	S. 77° E.	2.4	N. 7° E.	3.6
500	N. 33° W.	4.7	S. 12° W.	4.9	S. 68° E.	3.8	N. 9° E.	5.1
750	N. 27° W.	5.4	S. 20° W.	5.0	S. 61° E.	4.5	N. 8° E.	5.9
1,000	N. 25° W.	5.3	S. 21° W.	4.9	S. 56° E.	4.0	N. 5° E.	5.9
1,500	N. 7° W.	4.4	S. 28° W.	5.2	S. 51° E.	2.8	N. 8° W.	6.4
2,000	N. 3° W.	4.6	S. 34° W.	4.5	S. 64° E.	0.4	N. 19° W.	7.7
2,500	N. 13° W.	5.8	S. 47° W.	4.3	N. 60° W.	1.4	N. 28° W.	8.1
3,000	N. 12° W.	6.8	S. 56° W.	4.7	N. 46° W.	3.2	N. 32° W.	9.7
3,500	N. 13° W.	7.9	S. 72° W.	5.5	N. 53° W.	3.9	N. 38° W.	11.8
4,000	N. 19° W.	10.4	S. 81° W.	5.4	N. 55° W.	4.3	N. 39° W.	12.9
4,500	N. 23° W.	11.8	N. 89° W.	5.3	N. 57° W.	5.0	N. 50° W.	14.8
5,000	N. 35° W.	12.7	N. 76° W.	5.6	N. 62° W.	5.7	N. 53° W.	14.2
6,000	N. 33° W.	14.2	N. 82° W.	7.3	N. 52° W.	6.7	N. 45° W.	16.6
7,000			N. 55° W.	5.0	N. 38° W.	7.3	N. 41° W.	16.6
8,000					N. 44° W.	7.9		
9,000					N. 58° W.	6.8		
10,000					N. 47° W.	6.0		
11,000					N. 33° E.	5.0		
12,000					N.	8.7		

AUTUMN

Altitude m. s. l.	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Surface	N. 51° W.	3.6	S. 19° W.	3.5	S. 55° E.	2.4	N. 23° W.	4.2
500	N. 50° W.	5.6	S. 30° W.	6.1	S. 51° E.	4.5	N. 20° W.	5.1
750	N. 47° W.	6.4	S. 39° W.	7.0	S. 40° E.	5.4	N. 20° W.	5.2
1,000	N. 47° W.	7.1	S. 46° W.	7.5	S. 34° E.	5.4	N. 22° W.	7.8
1,500	N. 42° W.	8.2	S. 56° W.	8.3	S. 13° E.	4.7	N. 25° W.	8.1
2,000	N. 46° W.	10.5	S. 69° W.	8.2	S. 21° W.	2.7	N. 32° W.	9.2
2,500	N. 44° W.	12.6	S. 83° W.	7.5	S. 64° W.	3.6	N. 36° W.	11.2
3,000	N. 38° W.	13.8	N. 86° W.	7.2	S. 74° W.	4.7	N. 41° W.	13.4
3,500	N. 39° W.	15.8	N. 83° W.	8.0	S. 79° W.	5.4	N. 43° W.	14.5
4,000	N. 39° W.	15.4	N. 78° W.	7.7	N. 85° W.	5.6	N. 37° W.	17.6
4,500	N. 36° W.	17.4	N. 73° W.	7.5	W.	7.1	N. 38° W.	17.3
5,000	N. 40° W.	15.8	N. 62° W.	8.6	S. 77° W.	8.7	N. 37° W.	16.7
6,000	N. 21° E.	14.3	N. 65° W.	9.5	N. 85° W.	9.7	N. 38° W.	14.0
7,000			N. 58° W.	7.9	N. 72° W.	10.9		
8,000			N. 48° W.	7.6				
9,000			N. 60° W.	7.1				
10,000			N. 40° W.	2.9				

YEAR

Altitude m. s. l.	Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4	
Surface	N. 65° W.	3.4	S. 10° W.	3.5	S. 76° E.	2.6	N. 15° W.	4.1
500	N. 61° W.	5.1	S. 22° W.	5.8	S. 69° E.	4.1	N. 14° W.	5.6
750	N. 55° W.	6.2	S. 30° W.	6.7	S. 61° E.	4.7	N. 9° W.	6.1
1,000	N. 53° W.	7.3	S. 39° W.	7.0	S. 54° E.	4.6	N. 13° W.	7.1
1,500	N. 49° W.	9.3	S. 52° W.	7.7	S. 43° E.	3.0	N. 25° W.	8.5
2,000	N. 50° W.	11.3	S. 67° W.	7.6	S. 12° E.	0.6	N. 34° W.	10.6
2,500	N. 49° W.	13.3	S. 79° W.	7.4	N. 77° W.	1.6	N. 44° W.	12.2
3,000	N. 46° W.	13.6	W.	7.8	N. 68° W.	3.0	N. 46° W.	13.7
3,500	N. 45° W.	14.1	W.	8.6	N. 68° W.	3.3	N. 51° W.	15.2
4,000	N. 42° W.	13.7	N. 82° W.	8.4	N. 67° W.	4.7	N. 53° W.	15.8
4,500	N. 40° W.	14.3	N. 76° W.	77.8	N. 71° W.	6.1	N. 51° W.	16.4
5,000	N. 41° W.	14.1	N. 66° W.	8.1	N. 74° W.	6.4	N. 53° W.	16.7
6,000	N. 26° W.	12.8	N. 68° W.	9.2	N. 60° W.	6.7	N. 53° W.	16.4
7,000	N. 42° W.	12.6	N. 57° W.	7.2	N. 58° W.	7.3	N. 51° W.	18.4
8,000	N. 40° W.	11.7	N. 55° W.	7.0	N. 53° W.	8.1		
9,000	N. 6° W.	11.2	N. 60° W.	7.1	N. 59° W.	8.4		
10,000			N. 40° W.	2.9	N. 72° W.	7.8		
11,000					N. 36° W.	3.4		
12,000					N. 43° W.	8.0		

STATISTICAL CORRELATIONS OF WEATHER INFLUENCE ON CROP YIELDS

By J. B. KINCER and W. A. MATTICE

[Weather Bureau, Washington, D. C., March 14, 1928]

At the April, 1927, meeting of the American Meteorological Society, in Washington, the senior author outlined a method of multiple correlations of weather data with crop yields, that, so far as known, has not been employed heretofore by investigators in this field. The data used were several phases of weather in North Dakota in relation to the yield of spring wheat in that State, and since that presentation the authors, jointly, have applied the method to other crops in different States, and on weekly, biweekly, and monthly units of time for the weather variants, with very satisfactory results.

Weather, in the aggregate, for a given period of time as affecting plant growth, is a composite of many phases, such as temperature, rainfall, sunshine, wind, relative humidity, etc. There are also subphases, such as the mean temperature, mean of the daily maxima and of the daily minima, mean daily range, etc. Growing crops are influenced more or less by all of these phases which, in combination, make up the weather of the season. It is also well known that there are critical periods of growth, during which certain weather influences are more marked than during other times. These critical periods, in some crops at least, are of comparatively short duration and, consequently, it is necessary for best results to use weather variants based on similar short intervals of time, that their greater importance may be reflected in the final result. In most weather and crop correlations the month is used as the basic unit of time, principally by reason of the fact that weather data are usually compiled and published in this way. It is preferable, however, that shorter intervals of time be used in most cases.

The limitations of statistical correlations in studying the influence of weather on crops obtain, to a considerable extent, because of the large number of weather phases, all, or most of which, apparently have more or less influence on yield, and also because of the varying importance of different periods of growth, necessitating the use of comparatively short time intervals. These, combined, usually give a much larger number of variants than can be handled conveniently by the usual correlation methods. The system used in this study segregates, or picks out, from a large number of weather variants, those which, in combination with certain others, contribute to the augmentation of the final multiple coefficient, and discards those which do not make such contribution. By this means a limited number of weather variants is selected, for which it is possible to make a final multiple correlation; and many others, which show an apparent significant relation to yield when correlated separately with it, are discarded. We shall first outline the method as applied to 15 weather variants in North Dakota in relation to the yield of spring wheat in that State, taking the month as the time unit. We shall then apply it to 24 weather variables for the State of Ohio in relation to the yield of corn, on a weekly and biweekly basis.

Table 1 shows the 15 North Dakota weather variants used for the 25 years from 1900 to 1924, inclusive, arranged in order of the magnitude of the correlation coefficients with yield, separately, or as individual weather phases. It will be noted that for these 15 sets of weather data, the highest correlation, −0.66, is for the percentage of possible sunshine in July, and the lowest, +0.47, is for the mean 7 p. m. relative humidity for June. Thus we have 15 different weather phases whose correlations, separately, with spring-wheat yields, range from 0.47 to 0.66, all being apparently significant if the individual correlations with yield are accepted as criteria.

It is not feasible to make a multiple correlation to include all these with the yield. The magnitude of computations is prohibitive, and at the same time the number of variants is so large as to materially vitiate the value of the coefficient obtained. Furthermore, there is excellent a priori reason for believing that some of the weather phases are so closely associated with others that their apparent importance, as shown by separate correlation with yield, is, in reality, much less than is suggested by the magnitude of the coefficient. In many cases these, though showing a substantial correlation with the yield, contribute little or nothing to the final result when included in combination with their associate data.

Our problem, then, is to select from the mass of data only those which, in the final analysis, prove of real value for the purpose of computing or estimating yields. To do this we first select from Table 1 the variant that is apparently most important, as indicated by the magnitude of its coefficient with yield; in this case, the percentage of possible sunshine in July, with a coefficient of −0.66. We then compute the multiple correlation coefficient for this variant and each of the others, successively, with the yield. The results are shown in Table 2 (a), column 3, which indicate that e combined with a gives the highest correlation, 0.80; that is, by combining these variants, and using two values, instead of one, the coefficient is increased from 0.66 to 0.80. We next compute the yield from these two variants by the usual regression equation; the result is shown in Table 3, column a_1.

We designate this new variant a "weather index" (a_1), drop a and e from those under consideration (Table 1), substitute a_1 as a new base, and proceed as before. The results of the second computations are shown in Table 2 (b), column 3, where three sets—Ra_1bx, Ra_1dx, and Ra_1fx—give approximately the same correlation, 0.84. (R represents the multiple coefficient.) However, f does not correlate quite so closely with the remaining weather variants as do b and d; consequently, f is added to a_1 for computation of a third base (or a_2), as before. The resulting data are shown in Table 3 (under a_2), whose straight correlation coefficient with the yield is +0.84, corresponding with the highest multiple correlation in Table 2 (b). With this new base, (a_2), multiple correlations are made with the remaining variables, one at a time, as before, and the highest obtained is through adding d ($R=0.88$) shown in Table 2 (c), column 3. The process is again repeated, the results being shown in division d of this table, column 3, where the final correlation coefficient is 0.89.

Excellent checks as to accuracy of computation are afforded throughout the process. The straight coefficient of correlation between the successive weather indices a_1, a_2, a_3, and a_4 (Table 3) and the yield should agree, approximately, with the highest multiple coefficient in column 3 of the corresponding divisions of Table 2, while the successive means of the weather indices should be substantially the same as the mean of the yield. (See the several means in Table 3.) Again, the final combined multiple coefficient, when all of the selected data are used, in correlation with the yield, should be the same as the straight single coefficient of the final set of weather indices (a_4) with the yield.

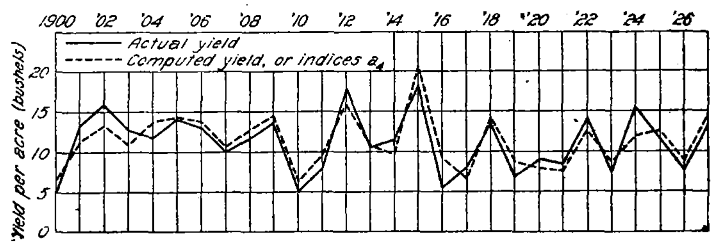

FIG. 1.—Comparison of actual and computed yields of spring wheat in North Dakota

Figure 1 affords a graphic comparison of computed yields from the selected five sets of weather data for the 25-year period 1900–1924 with the actual yield. It will be noted that there are included in this graph the years 1925, 1926, and 1927. This projection was made by applying the several constants obtained for the 1900–1924 data to the same weather phases for the succeeding three years, and was intended to test the results through application to years not included in the original equation. The constants established by the regression equation apply very nicely to these succeeding three years.

The Wallace-Snedecor [1] method of multiple correlations was used in these computations. By this method the multiple coefficient for a and e (Table 2 (a), column 3) is found by solving the following equation:

$$R^2=\beta xa.\ rax.+\beta xe.\ rex. \tag{1}$$

and the weather indices (a_1, Table 3) from the following:

$$X=Mx+\beta xa\,\frac{\sigma x}{\sigma a}\,(A-M_A)+\beta xe\,\frac{\sigma x}{\sigma e}\,(E-M_E) \tag{2}$$

where A and E, respectively, are the weather data for the several years, M_A and M_E, the means for these, and Mx, the mean of the yields. The betas are found by solving the simultaneous equation,

$$\begin{aligned} \beta xa + rae.\ \beta xe &= rax \\ rae.\ \beta xa + \quad \beta xe &= rex \end{aligned} \tag{3}$$

While the final weather indices a_4 (Table 3) represent for the several years the computed yields for the five weather variants selected, to project the curve into the future, or for the purpose of applying the constants to

[1] Wallace, H. A., and Snedecor, George W. 1925. Correlation and machine calculation. Official publication, Iowa State College, 23: No. 35.

future years, it is more convenient to make a single multiple correlation of these five variants, and establish constants for each in the usual way by means of a regression equation. This may be done by enlarging the equations to include all five weather variants, instead of two, as here given. By doing this the multiple coefficient is 0.89, and the regression constants are found to be as follows: $-0.270A, +0.788E, -0.414F, -0.473D, +0.090M, +77.5$. The several weather data, used are (a) percentage of possible sunshine in July; (e) rainfall, April to June; (f) mean temperature, June; (d) mean temperature, July, and (*m*) percentage of possible sunshine, June. In Table 1, the rainfall data, mean temperature, and the number of cloudy days, represent State averages as computed from all Weather Bureau stations, and the other data as computed from first-order stations only, represented by Williston, Bismarck, and Devils Lake, N. Dak., and Moorhead, Minn.

It happens occasionally that weather conditions may not be directly responsible for partial crop failures, and in such case it appears preferable, in correlation work, not to include such years, when the facts are known, in computing coefficients and regression equations. For example, in the series of years covered by this study of spring wheat yields in North Dakota, 1916 stands out as a case in point. In that year the weather was favorable and prospects for a fairly good crop bright until near harvest time, when, within a few days, black rust played havoc with the yield. If we omit 1916, and make our correlation include the other 24 years, some changes are shown in the weather data selected as the most important, but at the same time, the final coefficient is increased from 0.89 to0.93.

WEATHER AND CORN YIELDS IN OHIO

Reference has been made to the desirability of studying the effect of weather on crop yields with the basic weather variants compiled on unit periods of time shorter than the month. To apply the system used in the case of North Dakota and spring wheat to weather records and corn yields in Ohio, data, including the several weather phases, for the latter State were compiled on a weekly and biweekly basis, and straight correlations made with yield for numerous periods and many different weather phases. In this case a large number showed apparently significant correlations, as indicated in Table 4, where 24 separate coefficients, ranging from 0.40 to 0.66, are shown for the period from 1900 to 1925.

Table 5 for Ohio is similar to Table 3 for North Dakota, and the previously given explanation of the latter applies to this also. It will be noted that the selection of *a*, *c*, *l*, *n*, *q*, and *o* (from Table 4), raises the base coefficient successively from 0.66 to 0.84, 0.89, 0.91, 0.92, and 0.93. No other combination gives an increase above 0.93, and we therefore conclude that this is the maximum value that can be obtained from the data in hand. However, a coefficient of 0.93, for so long a period, with no year or data of any kind omitted, is very satisfactory. The basic data of rainfall for Ohio were compiled from State averages of records for all stations, and the other values from records of the first-order stations at Cincinnati, Columbus, and Cleveland, well distributed across the State. Figure 2 affords a graphic comparison of the computed yields of corn with the actual yields for the 25-year period.

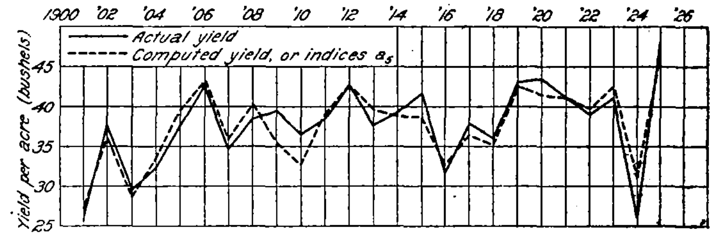

FIG. 2.—Comparison of actual and computed yields of corn in Ohio

THE IMPORTANCE OF HIGH CORRELATIONS

In the correlation of weather data with crop yields the importance of a high coefficient, and a comparatively small increase in one already relatively high which may be obtained by adding additional data, are not always appreciated. The relative value of a correlation for estimating purposes increases much more rapidly than the increase in the coefficient itself. In the absence of information as to the condition of a growing crop, or of factors influencing its development, the average yield is the best indicator as to what the harvest is likely to be, and the standard deviation of yields from this average for a series of years affords a measure of the accuracy of predictions by this method. However, a computation or estimate based on something other and better than the mean will show a standard deviation from the actual yields smaller than the standard deviations of yields.

The relative value of correlations represented by coefficients of different magnitudes may be determined in this way: that is, by comparing the standard deviation of the residuals of actual yields from computed yields, with the standard deviation of yields, when the regression equations are based on sets of data having various degrees of correlation, such as the several weather indices shown in Tables 3 and 5. Yield estimates from data having a correlation coefficient of 0.40 reduces the standard deviation less than 10 per cent; 0.50, about 13 per cent; 0.60, about 20 per cent; 0.70, 29 per cent; 0.80, 40 per cent; 0.90, 56 per cent; 0.95, 69 per cent; and 0.98, 80 per cent. Thus the raising of the coefficient in the case of corn in Ohio four points, from 0.89 to 0.93, by adding the last three weather phases, has as much value as raising the base *a* coefficient nine points from 0.66 to 0.75. It is also equivalent to an increase of 16 points in raising a coefficient from 0.40 to 0.56.

TABLE 1.—*North Dakota*

Year	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
1900	74	9	5	68	3	67	29	74	40	26	27	5	68	42	42
1901	65	7	6	71	7	62	28	79	43	20	22	6	51	63	63
1902	70	3	12	68	8	58	22	56	62	22	25	4	56	50	61
1903	71	3	9	67	6	62	25	58	50	23	24	6	61	50	48
1904	73	3	8	64	9	61	23	56	53	21	26	6	56	47	57
1905	66	1	11	66	8	60	24	47	54	20	22	5	46	61	64
1906	70	3	14	67	10	62	22	40	62	20	24	10	54	64	65
1907	68	1	9	66	4	62	25	50	52	23	24	4	56	60	58
1908	68	7	11	69	8	60	23	53	55	20	28	8	54	46	60
1909	65	4	10	67	8	63	24	57	53	21	22	7	64	64	62
1910	75	19	8	70	4	67	27	62	46	27	29	4	72	46	42
1911	76	7	8	65	7	67	26	64	52	24	27	3	61	44	58
1912	66	6	11	66	9	62	22	46	56	24	23	6	68	62	54
1913	70	5	11	66	5	66	24	51	52	25	25	6	70	53	51
1914	79	8	7	72	10	62	26	70	50	21	24	3	69	54	64
1915	58	0	11	62	9	57	22	48	52	22	21	8	51	58	59
1916	76	5	9	73	8	58	24	53	47	21	22	3	58	60	58
1917	77	13	4	71	4	60	29	74	32	26	28	3	66	44	44
1918	64	7	10	66	6	63	25	54	50	24	25	7	70	52	51
1919	73	12	7	71	7	67	24	70	48	23	26	3	72	45	56
1920	81	4	8	68	6	62	25	64	44	22	24	2	70	50	55
1921	77	13	8	71	8	68	23	69	48	22	24	4	67	50	57
1922	72	5	10	66	8	64	20	57	56	22	24	4	67	52	56
1923	74	7	6	71	7	66	25	72	43	23	24	4	71	56	52
1924	75	1	9	66	8	59	24	54	44	22	23	4	53	51	55
Means	71	6	9	68	7	63	24	59	50	23	25	5	62	53	56
σ	5.31	4.38	2.27	2.71	1.88	3.15	2.22	10.02	6.52	2.00	2.12	1.87	7.74	6.76	6.42
rx's	−.66	−.64	+.62	−.60	+.57	−.57	−.57	−.55	+.55	−.54	−.54	+.52	−.48	+.48	+.47

a, Percentage of possible sunshine, July.
b, Number of days with maximum temperature above 90°, June 1 to July 31.
c, Number of cloudy days, May.
d, Mean temperature, July.
e, Total rainfall, April to June, inclusive.
f, Mean temperature, June.
g, Mean daily temperature range, May.
h, Percentage of possible sunshine, May.
i, Mean 7 p. m. relative humidity, May.
j, Mean daily temperature range, June.
k, Mean daily temperature range, July.
l, Number of cloudy days, July.
m, Percentage of possible sunshine, June.
n, Mean 7 p. m. relative humidity, July.
o, Mean 7 p. m. relative humidity, June.
rx's, Coefficients of correlation with yield of spring wheat.

TABLE 2

(a) 1	(a) 2	(a) 3	(b) 1	(b) 2	(b) 3
rax−0.66	rab+0.43	Rabx 0.77	ra_1x+0.81	ra_1b−0.54	Ra_1bx 0.84
rbx− .64	rac− .51	Racx .74	rbx− .64	ra_1c+ .66	Ra_1cx .82
rcx+ .62	rad+ .53	Radx .72	rcx+ .62	ra_1d− .54	Ra_1dx .84
rdx− .60	rae− .18	Raex .80	rdx− .60	ra_1f− .46	Ra_1fx .84
rex+ .57	raf+ .32	Rafx .76	rfx− .57	ra_1g− .60	Ra_1gx .82
rfx− .57	rag+ .32	Ragx .76	rgx− .57	ra_1h− .57	Ra_1hx .82
rgx− .57	rah+ .48	Rahx .71	rhx− .55	ra_1i+ .64	Ra_1ix .81
rhx− .55	rai− .42	Raix .72	rix+ .55	ra_1j− .60	Ra_1jx .81
rix+ .55	raj+ .20	Rajx .76	rjx− .54	ra_1k− .58	Ra_1kx .82
rjx− .54	rak+ .39	Rakx .73	rkx− .54	ra_1l+ .64	Ra_1lx .81
rkx− .54	ral− .67	Ralx .67	rlx+ .52	ra_1m− .54	Ra_1mx .81
rlx+ .52	ram+ .45	Ramx .69	rmx− .48	ra_1n+ .63	Ra_1nx .81
rmx− .48	ran− .52	Ranx .68	rnx+ .48	ra_1o+ .65	Ra_1ox .81
rnx+ .48	rao− .28	Raox .73	rox+ .47		
rox+ .47					

(c) 1	(c) 2	(c) 3	(d) 1	(d) 2	(d) 3
ra_2x+0.84	ra_2b−0.63	Ra_2bx 0.85	ra_3x+0.88	ra_3b−0.71	Ra_3bx 0.88
rbx− .64	ra_2c+ .65	Ra_2cx .84	rbx− .64	ra_3c+ .69	Ra_3cx .88
rcx+ .62	ra_2d− .43	Ra_2dx .88	rcx+ .62	ra_3g− .60	Ra_3gx .88
rdx− .60	ra_2g− .58	Ra_2gx .85	rgx− .57	ra_3h− .69	Ra_3hx .98
rgx− .57	ra_2h− .60	Ra_2hx .84	rhx− .55	ra_3i+ .62	Ra_3ix .88
rhx− .55	ra_2i+ .59	Ra_2ix .84	rix+ .55	ra_3j− .51	Ra_3jx .89
rix+ .55	ra_2j− .63	Ra_2jx .84	rjx− .54	ra_3k− .54	Ra_3kx .88
rjx− .54	ra_2k− .58	Ra_2kx .84	rkx− .54	ra_3l+ .63	Ra_3lx .88
rkx− .54	ra_2l+ .57	Ra_2lx .84	rlx+ .52	ra_3m− .65	Ra_3mx .89
rlx+ .52	ra_2m− .73	Ra_2mx .86	rmx− .48	ra_3n+ .54	Ra_3nx .88
rmx− .48	ra_2n+ .63	Ra_2nx .84	rnx+ .48	ra_3o+ .56	Ra_3ox .88
rnx+ .48	ra_2o+ .67	Ra_2ox .85	rox+ .47		
rox+ .47					

Column 1: Correlation coefficients of the several series of weather data (Table 1) with yield of spring wheat.
Column 2. Coefficients of intercorrelations of weather data in Table 1.
Column 3. Multiple coefficients of base weather data, or indices, and those remaining, as indicated by designations *a*, *b*, *c*, etc., in Table 1.

TABLE 3

	x	a_1	a_2	a_3	a_4	v
1900	4.9	6.2	5.8	6.5	6.3	+1.4
1901	13.1	13.6	13.7	12.1	11.2	−1.9
1902	15.9	12.5	13.9	13.5	13.2	−2.7
1903	12.7	10.2	10.7	11.1	10.9	−1.8
1904	11.8	12.2	12.8	14.1	13.8	+2.0
1905	14.0	14.2	14.8	15.0	14.1	+0.1
1906	13.0	14.3	14.3	14.2	13.9	+0.9
1907	10.0	9.6	10.2	11.1	10.5	+0.5
1908	11.6	13.4	14.1	13.2	12.7	+1.1
1909	13.7	14.6	14.2	14.1	14.4	+0.7
1910	5.0	6.7	6.2	6.1	6.1	+1.1
1911	8.0	9.1	8.3	9.9	9.6	+1.6
1912	18.0	15.1	15.0	15.2	16.0	−2.0
1913	10.5	9.7	9.1	10.2	10.6	+0.1
1914	11.2	10.7	11.1	9.5	9.7	−1.5
1915	18.2	18.3	19.2	20.4	20.5	+2.3
1916	5.5	10.1	11.8	9.7	9.1	+3.6
1917	8.0	5.9	7.6	6.9	6.6	−1.4
1918	13.6	13.1	12.9	13.4	14.2	+0.6
1919	6.9	10.3	9.3	8.3	8.6	+1.7
1920	9.0	6.2	7.3	7.8	7.9	−1.1
1921	8.5	9.7	8.5	7.6	7.5	−1.0
1922	14.1	11.7	11.4	12.1	12.5	−1.6
1923	7.4	9.9	9.3	8.3	8.6	+1.2
1924	15.7	10.5	11.9	12.6	12.0	−3.7
Mean	11.2	11.1	11.3	11.3	11.2	
σ's	3.76	3.02	3.15	3.31	3.34	1.75
rx's		+.81	+.84	+.88	+.89	

x, Yield of spring wheat, bushels per acre, North Dakota.
a_1, Weather indices computed from a_1 and *e* (Table 1), by multiple correlation. (See also Table 2 (a), column 3).
a_2, Weather indices computed from *a* and *f* (including *a*, *e*, and *f*, Table 1), by multiple correlation. (See also Table 2 (b), column 3).
a_3, Weather indices computed from a_2 and *d*, (including *a*, *e*, *f*, and *d*, Table 1), by multiple correlation. (See also Table 2 (c), column 3).
a_4, Weather indices (or final computation of yields) from a_3 and *m* (including *a*, *e*, *f*, *d*, and *m*, Table 1), by multiple correlation. (See also Table 2 (d), column 3).
v, Variations of a_4 (final computation of yields) from *x* (actual yield).
rx's, Coefficient of correlation of successive weather indices with yield of spring wheat (*x*).

TABLE 4.—*Ohio*

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	w	y	z
1901	49	74	45	0.1	63	82	27	73	63	56	67	0.1	67	64	93	83	0.6	62	60	82	0.6	1.9	0.7	1.3
1902	64	53	54	0.8	72	79	47	78	60	62	76	0.8	69	68	85	75	1.0	55	71	84	1.8	1.1	2.6	0.8
1903	49	71	41	0.3	72	86	47	76	48	65	72	0.6	50	69	84	75	1.6	70	57	68	1.2	2.8	1.8	0.3
1904	53	70	45	0.4	72	81	51	78	54	63	72	0.7	63	70	78	69	0.3	66	59	76	0.3	2.3	1.0	0.8
1905	66	66	66	1.4	73	82	51	76	75	64	81	1.0	62	68	78	70	1.3	66	64	79	0.7	2.2	1.7	3.2
1906	76	61	61	2.0	70	88	64	85	68	62	81	0.6	76	76	77	70	1.0	57	64	74	1.6	1.8	2.2	3.0
1907	64	64	38	0.5	63	78	43	67	66	56	81	1.6	38	60	82	74	0.9	65	61	74	1.7	2.4	3.3	1.0
1908	61	62	81	1.3	79	77	55	80	59	69	74	0.8	75	71	84	75	0.2	58	71	74	1.3	1.1	2.1	2.2
1909	58	63	59	0.3	76	81	48	76	74	68	78	0.9	47	69	80	71	1.5	72	57	77	0.8	2.9	1.7	2.6
1910	58	64	51	0.3	64	84	55	66	51	55	74	0.9	43	58	86	77	0.7	68	53	73	0.4	1.4	1.3	0.5
1911	57	58	75	0.3	83	77	41	81	63	73	76	1.0	61	72	78	67	1.0	65	60	80	0.6	2.0	1.6	1.7
1912	74	68	62	1.5	76	82	58	72	77	67	74	1.2	89	63	82	73	0	46	62	80	2.0	1.0	3.2	1.9
1913	59	70	62	0.8	73	81	54	73	62	65	67	2.1	83	63	84	74	0.3	61	66	82	1.0	1.6	3.1	1.2
1914	61	52	75	1.3	82	84	33	85	48	72	84	1.0	78	75	89	79	1.0	58	78	80	0.4	1.4	1.4	1.7
1915	74	75	31	0.9	66	73	48	74	72	59	76	1.6	72	65	80	71	1.6	65	81	77	2.8	3.2	4.4	1.9
1916	69	73	53	1.2	74	87	42	70	60	66	69	0.2	56	62	91	80	2.1	68	52	74	1.1	3.5	1.3	1.6
1917	66	74	46	0.4	71	80	35	75	61	63	72	1.3	53	67	86	77	1.5	67	59	71	1.0	4.6	2.3	1.0
1918	60	69	64	0.7	85	86	56	77	56	76	59	0.5	68	69	87	78	0.9	51	60	79	0.4	1.6	0.9	1.1
1919	61	54	96	1.6	84	82	59	82	65	73	78	1.2	77	74	87	78	0.6	69	59	87	2.0	0.6	3.2	2.6
1920	71	59	67	1.3	78	76	38	72	79	68	78	1.0	60	63	79	70	0.7	57	57	87	1.0	1.0	2.0	2.5
9121	65	72	84	0.8	82	79	94	74	70	72	79	1.2	69	65	89	78	0.3	70	72	82	0.7	1.0	1.9	2.1
1922	58	61	76	0.9	75	81	58	81	52	66	72	1.2	59	72	84	75	0.6	63	55	82	0.8	1.1	2.0	1.0
1923	66	51	89	0.6	81	75	54	81	66	71	72	0.8	74	72	80	71	1.1	68	64	75	0.4	1.2	1.2	1.4
1924	59	73	45	0.5	65	85	52	71	56	57	72	0.8	55	62	84	74	2.2	71	62	77	0.2	3.0	1.0	0.8
1925	70	44	88	1.1	79	69	91	90	64	68	79	1.3	77	80	78	70	0.5	52	75	83	1.2	0.5	2.5	2.0
Means	63	64	62	0.9	74	81	52	77	63	65	75	1.0	65	68	83	74	0.9	63	63	78	1.0	1.9	2.0	1.6
σ's	7.07	8.32	17.16	0.49	6.57	4.44	14.76	5.64	8.55	5.73	5.40	0.43	12.54	5.30	4.36	3.89	0.55	6.77	7.11	4.71	0.63	0.98	0.88	0.77
rx's	+.66	−.61	+.61	+.57	+.53	−.53	+.50	+.50	+.49	+.48	+.48	+.48	+.47	+.46	−.45	−.42	−.42	−.41	+.40	+.40	+.40	−.50	+.52	+.58

a, P. m. relative humidity for the week ending Aug. 11.
b, P. m. relative humidity for the week ending June 2.
c, Percentage of possible sunshine for the week ending June 2.
d, Total precipitation for the week ending Aug. 11.
e, Maximum temperatures for the week ending June 2.
f, Maximum temperatures for the week ending Aug. 25.
g, Percentage of possible sunshine for the week ending Apr. 7.
h, Maximum temperatures for the week ending June 9.
i, P. m. relative humidity for the week ending Aug. 18.
j, Mean temperatures for the week ending June 2.
k, Maximum temperatures for the week ending Sept. 22.
l, Total precipitation for the week ending July 14.
m, Percentage of possible sunshine for the week ending June 9.
n, Mean temperatures for the week ending June 9.
o, Maximum temperatures for the week ending July 28.
p, Mean temperatures for the week ending July 28.
q, Total precipitation for the week ending June 9.
r, P. m. relative humidity for the week ending June 9.
s, Maximum temperatures for the week ending Apr. 28.
t, Maximum temperatures for the week ending June 16.
u, Total precipitation for the week ending July 21.
w, Total precipitation for the two weeks June 2–16.
y, Total precipitation for the two weeks July 14–28.
z, Total precipitation for the two weeks Aug. 11–25.

TABLE 5

	X	a_1	a_2	a_3	a_4	a_5	V
1901	26.1	28.9	26.6	26.5	27.7	26.5	+0.4
1902	38.0	36.9	36.4	36.5	36.5	36.2	−1.8
1903	29.6	28.3	27.8	28.6	28.2	28.6	−1.0
1904	32.5	30.6	30.3	31.1	32.5	33.7	+1.2
1905	37.8	39.7	39.6	39.5	38.9	39.7	+1.9
1906	42.6	43.3	41.5	42.8	42.4	43.2	+0.6
1907	34.6	34.4	36.9	35.4	35.6	35.9	+1.3
1908	38.5	39.9	39.1	39.6	40.6	40.2	+1.7
1909	39.5	35.0	35.0	35.4	34.7	35.4	−4.1
1910	36.5	33.8	33.9	32.2	32.9	32.6	−3.9
1911	38.6	37.2	37.3	38.1	38.0	38.9	+0.3
1912	42.8	42.6	43.0	41.7	42.9	42.8	0
1913	37.5	36.0	40.1	39.0	39.9	39.6	+2.1
1914	39.1	38.9	38.9	40.2	40.0	38.8	−0.3
1915	41.5	37.7	39.9	39.2	38.2	38.7	−2.8
1916	31.5	39.0	36.2	35.2	33.6	32.4	+0.9
1917	38.0	36.5	37.8	37.6	36.8	36.3	−1.7
1918	36.0	36.7	35.1	35.4	35.6	35.0	−1.0
1919	43.0	42.3	42.7	43.5	43.7	42.6	−0.4
1920	43.4	42.0	41.7	40.5	40.7	41.2	−2.2
1921	41.0	42.1	42.5	41.6	42.4	41.0	0
1922	39.0	37.8	38.6	39.3	39.8	39.5	+0.5

TABLE 5—Continued

	X	a_1	a_2	O_3	a_4	a_5	V
1923	41.0	43.3	42.2	42.7	42.2	42.5	+1.5
1924	26.0	33.3	33.1	32.2	30.7	30.9	+4.9
1925	48.0	45.0	45.5	47.3	47.4	47.7	−0.3
Means	37.7	37.6	37.7	37.6	37.7	37.6	--------
σ's	5.21	4.41	4.63	4.78	4.82	4.86	1.95
rx's	--------	.84	.89	.91	.92	.93	--------

X, Yield of corn, bushels per acre, Ohio.
a_1, Weather indices computed from a and c (Table 4) by multiple correlation.
a_2, Weather indices computed from a_1 and l (including a, c, and l, Table 4), by multiple correlation.
a_3, Weather indices computed from a_2 and n (including a, c, l, and n, Table 4), by multiple correlation.
a_4, Weather indices computed from a_3 and q (including a, c, l, n, and q, Table 4), by multiple correlation.
a_5, Weather indices (or final computation of yields) from a_4 and o (including a, c, l, n, q, and o, Table 4), by multiple correlation.
V, Variations of a_5 (final computation of yields) from x (actual yield).
rx's, Coefficient of correlation of successive weather indices with yield of corn (x).